The implementation of universal newborn hearing screening programs has increased the number of infants diagnosed with hearing loss and referred for amplification in the first few weeks of life. There is compelling evidence that children born with hearing loss who have been identified and begun intervention by 6 months of age will have significantly better language development than their later-identified peers.1-3

The challenges of fitting appropriate amplification on this population include limited behavioral response to sound, possible complicating middle ear fluid, parental uncertainties, possible existence of additional handicaps, and limited resources to support and pay for hearing aids. Despite these issues, there is consensus that the diagnosis of congenital hearing loss should be completed in the first 3 months of life and be followed immediately with the consideration of hearing aid use.4

As access to follow-up from newborn hearing screening improves, pediatric audiologists are faced with recommending technology for infants during their early weeks of life. The options available to them are expanding rapidly as amplification technology grows and diversifies. Outcome studies of children fitted with advanced amplification features are not common and cannot keep up with the features being introduced to the market. Most infants are fitted with the goal of providing audibility for environmental speech to enhance speech and language development and with the expectation that patients will use their hearing aids daily.

The pediatric audiologist's role is to share information on hearing loss and available amplification technology with the parents and their medical and support team. Parents depend on various professionals to acquire the information and tools they need to become empowered, informed consumers. Reaching decisions about the choice of technology for an infant includes examining available features and selecting what might be the best fit for the infant given all the available information and circumstances.

**PRE-SELECTION AND SELECTION ISSUES**

The pre-selection process begins with examining hearing aid options, including style, type, and features. The style and physical fit will be determined by the degree of the loss and the potential for growth of the outer ear. Behind-the-ear (BTE) hearing aids requiring custom earmolds are the accepted standard for infants and young children. Historically, the challenge of fitting very small ears that are growing rapidly has been feedback when the mold allows a slit leak of the amplified signal.

The frequency with which earmolds must be replaced is directly proportional to the child’s growth rate and the amount of gain in the hearing aid. In young infants, new earmolds may be needed as often as every 4 to 6 weeks. Feedback-suppression technology may extend the life of earmolds for infants and should be considered for use; however, audibility must not be compromised. Feedback-suppression strategies that employ an active process and multiple frequency bands are common features of today's digital hearing aids.

Infants with bilateral hearing loss should be bilaterally fitted unless contraindicated for medical reasons, such as chronic ear drainage or significant unilateral external or internal ear malformation. The options for the type of amplification include air- and bone-conduction hearing aids, implantable hearing aids, FM transmission, and cochlear implants. Most children are fitted with air-conduction devices unless a condition such as bilateral atresia, anotia, or chronic otitis media precludes the use of a traditional earmold.

A bone-conduction aid is often the only alternative for children with such conditions. Traditional bone-conduction instruments offer limited signal-processing options and may not be flexible enough acoustically to meet a young child’s changing needs.

An alternative to traditional bone-conduction hearing aids is the bone-anchored hearing aid (Baha), which has a titanium screw surgically embedded in the mastoid bone. The titanium screw osseo-integrates into the bone, allowing the hearing aid, including the vibrator, to be attached to a plastic bayonet coupling inserted into the titanium abutment that passes through the skin. The Baha is an alternative to traditional bone-conduction aids for patients who have a permanent need for bone-conduction transmission of sound.5 The surgically implanted Baha is FDA approved for age 5 and older; a soft-band version that does not require surgery is a good option for young infants. The soft-band Baha has the added advantage of allowing for binaural fitting to minimize the head shadow effect.6

The benefits of cochlear implantation (CI) for children age 12 months or older with severe to profound hearing loss are well established.7,8 Children are CI candidates if traditional hearing aids do not give them the benefit necessary to acquire normal speech and language skills. The CI candidacy process requires using hearing aids during the first few months of life. While bilateral cochlear implants...
are increasingly considered for children, many children will continue to use a hearing aid in the non-implanted ear.

In choosing the most appropriate features of amplification, the audiologist needs to consider the unique needs of young children. Tamper-resistant battery doors are a basic safety feature for all young children. Volume control and/or program buttons should be deactivated or covered. Also, smaller, thinner instruments with pediatric-size earhooks may make retention easier, but they may compromise important features, including FM and direct audio input. Some parents may find the addition of a remote control helpful when a hearing aid setting needs to be modified quickly. For example, if an infant falls asleep causing hearing aid feedback, the parent may turn off the aid. Or a parent may want the option of accessing an FM program with a remote control.

The use of FM technology with hearing aids or cochlear implants can improve the signal-to-noise ratio from a primary speaker to a listener’s ear, an important goal for all people with hearing loss, but especially those in the midst of language acquisition. The development of ear-level FM technology has dramatically facilitated its use. And, while FM has traditionally been intended for school-aged children, its use with infants and toddlers can also enhance the child’s auditory access when distance, noise, or reverberation compromises the listening environment.

Many children, even some with a mild hearing loss, require a signal-to-noise ratio advantage as their ability to hear in noise is significantly affected. While there are few outcome data on FM use with infants, the prospect of direct input from a primary language model’s voice seems appealing in adverse listening conditions, such as a car, a stroller, or a backpack, and in noisy situations such as a playground or store. The FM input can be added to the information the child’s receives from the environment by means of an HA+FM setting.

It is important for infants and toddlers using FM to hear their own voice through the amplification microphone. Even if there is no immediate plan to use FM with an infant, this feature should be available on any child’s hearing aid since a direct audio input or FM system may be required in the future.

**SIGNAL PROCESSING OPTIONS**

Providing audibility and the best possible amplified signal is the ultimate goal of all amplification for children. Amplified sound should be consistently audible and comfortable. Providing an audible signal for incoming speech is a critical aspect of developing and maintaining aural/oral communication for children.

Amplification with flexible electroacoustic characteristics may be the single most important feature of amplification for infants. Not only is this population unable to give threshold behavioral responses to sound, but also young children are prone to middle ear disorders that may cause additional fluctuating hearing loss. Another variable, the dimensions of a child’s ear canal and therefore its resonance characteristics, changes significantly until a child is about 5 years of age. These factors may require changes in the
amplification signal over time, particularly in the areas of gain, frequency response, and output characteristics.

Wide dynamic range compression (WDRC) is now commonly used with infants and young children to provide more gain at low inputs and less gain at high inputs. It is better than linear amplification for ensuring audibility of soft speech and comfort for loud sounds.

Hearing aids must avoid distortion to optimize the quality of the speech signal and they must have an appropriate frequency bandwidth for the degree and slope of the child’s hearing loss. Stelmachowicz et al. found that hearing-impaired children require a wider frequency bandwidth than adults with similar hearing losses to perceive high-frequency speech sounds, particularly when listening to female or child talkers.16 However, Ching et al. found that children and adults with severe hearing loss did not benefit from maximal audibility in the high frequencies.17

While the optimal bandwidth remains a matter of debate, many hearing aids offer multiple frequency channels or bands as a way of independently processing different frequency ranges to meet the child’s needs. The optimal number of channels or bands may vary with the slope of the hearing loss and should be flexible enough to match the shape, or configuration, of the child’s hearing loss with requisite power to meet a predetermined target slope for gain and output.

Hearing aid manufacturers are rapidly introducing circuitry that can reduce gain of “noise,” with the goal of enhancing the clarity of speech, and hearing aids with automated directional algorithms designed to enhance speech intelligibility in noise. While these goals are admirable, the features may have the unintended consequences of reducing communication access for young children. Outcome-based research is needed to evaluate the use of this technology on young children.

**SELECTION AND FITTING**

The audiologist’s selection of the type, style, features, and circuitry of hearing aids should be based on the degree, configuration, and type of hearing loss, as well as consideration of economic factors and family preference. Once these choices have been made, the audiologist begins the fitting process, ensuring that the gain, frequency response, and maximum power output are adjusted appropriately for maximum audibility of speech to the child. With infants and young children, adjustments cannot be based entirely on behavioral responses or subjective feedback. It is imperative to use predetermined goals as targets to verify appropriate amplification settings.

In selecting a prescriptive method to use with a young child, the audiologist should decide based on the premise that the entire speech spectrum should be audible. The prescriptive methods chosen should reflect the type of signal processing used in the aid. If it’s a non-linear WDRC aid, the formula should reflect goals for speech audibility for different input levels. Methods meeting this requirement include the Desired Sensation Level (DSL v5.0) method18-20 and the National Acoustics Laboratory (NAL-NL1) method.21
<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Style</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Behind-the-ear style | Sits on top of the outer coupled directly to the ear with a custom fit earmold | ❖ Flexible as child grows  
❖ Durability  
❖ Decreased feedback | ❖ Retention on ear |
| In-the-ear style | All components in the ear | ❖ Cosmetically appealing | ❖ Easily outgrown causing feedback. Not appropriate for young children |
| Body-worn hearing aid style | Body-worn device coupled to ear with cords and earmold | ❖ Reduces feedback, appealing if head control is compromised | ❖ Microphone may not be at the ear for localization  
❖ Multiple parts make use cumbersome |
| Soft earmolds | Custom-made impression of external ear concha and lateral portion of canal made from durable, soft, silicone, or vinyl material | ❖ Easily replaced as child grows | ❖ Needs to be replaced with growth to minimize feedback |
| Binaural amplification | Fitting of hearing aids on both ears | ❖ Localization  
❖ Optimal performance in noise  
❖ Minimizes the risk of auditory deprivation | ❖ Cost  
❖ Management |
| **Type**    |             |            |             |
| Air-conduction aids | Amplified sound delivered into ear canal | ❖ Maximizes sound quality  
❖ Multiple signal processing strategies available | ❖ Limited use with external ear malformation  
❖ Limited use with chronic ear drainage |
| Bone-conduction aids | Amplified sound delivered directly into inner ear (cochlea) by way of vibration of skull from transducer placed the ear | ❖ Bypasses external and middle ear for external ear malformation and chronic ear drainage | ❖ Limited available signal processing options  
❖ Requires headband to hold firmly in place on mastoid |
| Cochlear implants | Surgically implanted device with externally worn processor that converts acoustic energy into electrical energy, stimulating the auditory nerve | ❖ Improved audibility of sound for individuals with limited benefit from hearing aids | ❖ FDA approved for 12 months of age and older  
❖ Only for severe-profound hearing loss  
❖ Requires surgical procedure |
| Implantable aids | Amplification device surgically implanted | ❖ Bone conduction device (Baha) FDA approved for age 5 and up. Prevents need for headband | ❖ Requires surgical procedure  
❖ Baha has external component  
❖ No air conduction device available for children in U.S. |
| **Amplification Features** |             |            |             |
| Multiple memories/programs | Capability of switching between amplification programs with push button or remote control | ❖ Added flexibility, good for fluctuating hearing loss  
❖ Can access multiple processing strategies or microphones | ❖ Need physical manipulation to change programs  
❖ Programs usually changed on personal preference/may not be practical for young children |
### Multiple microphones

- **What:** The capability of the hearing aid's microphones to reduce incoming signals from the back and sides of the listener.
- **Why:** Benefits in young children are unknown.
- **Effect:** Reduces input of environmental sounds and incidental listening.

### FM systems

- **What:** Assistive listening technology that allows the signal from a remote microphone to be sent directly to the ear of the listener.
- **Why:** Enhanced signal-to-noise ratio in noisy environments.
- **Effect:** Reduces input of environmental sounds and incidental listening, enhanced signal-to-noise ratio in noisy environments.

### Programmability

- **What:** The ability to manipulate the amplification of a signal in terms of frequency response, gain, and output characteristics according to the audiologic needs of the child.
- **Why:** Programmability is flexible and able to accommodate changing variables in a child's amplification needs.
- **Effect:** Requires use of additional equipment and accurate audiological information required to program appropriately.

### Signal Processing Strategies

<table>
<thead>
<tr>
<th>Signal Processing Strategies</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wide dynamic range compression (WDRC)</strong></td>
<td>Automatically adjusts gain for all input intensities, increased audibility of soft speech sounds at low input levels, less gain at high intensities may help limit overamplification, may be perceived as less powerful to experienced users, less gain at high intensities may be perceived as less powerful to experienced users, need a hearing aid with digital signal processing to achieve low compression threshold.</td>
</tr>
<tr>
<td><strong>Output limiting</strong></td>
<td>Limits output to intensities below which additional hearing damage can occur, ensures audibility and avoids loudness discomfort for the speech range inputs, reduces gain to avoid distortion of the speech range inputs, active feedback reduction now available.</td>
</tr>
<tr>
<td><strong>Multiple channels</strong></td>
<td>Frequency-shaping capabilities of the hearing aid, allows access to audibility of speech signals in the presence of some background noise, frequency transposition or compression enhancement, frequency transposition or compression.</td>
</tr>
<tr>
<td><strong>Noise reduction/Speech enhancement</strong></td>
<td>Frequency-shaping capabilities of the hearing aid, allows access to audibility of speech signals in the presence of some background noise, frequency transposition or compression enhancement, frequency transposition or compression.</td>
</tr>
</tbody>
</table>
After choosing an appropriate prescriptive method, the audiologist should pre-set the hearing aid to the target values for gain, output, and frequency response that have been established for the child’s auditory thresholds and ear canal volume. Pre-setting the hearing aids using coupler measurements is an important step in fitting amplification to small ear canals.

HEARING AID VERIFICATION

After the hearing aids have been pre-set, it is best to verify that they have been adjusted appropriately for a child, given that adults and children respond differently to the type and settings of amplification and there is no consensus about the optimal hearing aid characteristics for children. Several methods can be used, including probe-microphone measurements, coupler measurements, and sound field-aided testing.

Using a probe microphone is the most direct way to measure hearing aid performance in the ear of a child, as target values are matched based on the prescription method chosen. In addition, the entire frequency spectrum can be analyzed using this method. This method factors in individual ear differences based on the child’s ear canal size and resonant frequency. It requires only passive cooperation from the child, which reduces the variability in the responses as compared to sound field testing. Because this procedure is done with the hearing aid in the child’s ear, the parameters of the aid can be adjusted quickly and accurately. Using a real-ear-to-coupler difference (RECD) with age corrections can be a viable option to actual measured values from a child’s ear. However, these methods do not reflect the actual benefit of the hearing aid in terms of listening and speech understanding.

Doing sound field-aided testing involves obtaining behavioral responses to sound while the child is using amplification. This option is limited due to the need for behavioral responses. Infants under the developmental age of approximately 6 months cannot provide reliable behavioral responses, and the process is further limited because of the lack of definite test-retest variability estimates for sound field testing. In addition, this

Table 2. Hearing instrument orientation.

<table>
<thead>
<tr>
<th>Care:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean earmold; keep clear of debris</td>
</tr>
<tr>
<td>Protect from moisture; do not use while bathing or swimming</td>
</tr>
<tr>
<td>Overnight storage; may use dehumidifier case</td>
</tr>
<tr>
<td>Lock battery door to prevent battery ingestion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wearing schedule:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal: Full-time use during waking hours</td>
</tr>
<tr>
<td>May take off or turn off while sleeping</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insertion</td>
</tr>
<tr>
<td>Removal</td>
</tr>
<tr>
<td>Off/on</td>
</tr>
<tr>
<td>Volume settings and multiple memories, if applicable</td>
</tr>
<tr>
<td>Insertion and removal of batteries</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Troubleshooting:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery life</td>
</tr>
<tr>
<td>Good fit to prevent feedback</td>
</tr>
<tr>
<td>Keep earmold opening clear of debris</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Assistive device use (if applicable):</th>
</tr>
</thead>
<tbody>
<tr>
<td>FM coupling and use</td>
</tr>
<tr>
<td>Telephone coupling and use</td>
</tr>
</tbody>
</table>
Available aided speech-perception measures are limited for infants; however, the Low-Verbal Early Speech Perception task and the Early Speech Perception Task (ESP), the Pediatric Speech Intelligibility Test (PSI), and Northwestern University’s Children’s Perception of Speech Test (NU-CHIPS) may be used for preschool children. There are also questionnaires available for parents and caregivers, including Functional Auditory Performance Indicators (FAPi) and the Infant Toddler Meaningful Auditory Integration Scale (IT-MAIS).

FOLLOW-UP

The child’s managing audiologist should provide ongoing support for audiometric and amplification assessment, troubleshooting, and adjustment. The child should be followed at least every 3 months during the first 2 years of life and at least every 3 to 6 months from age 2 to 5 years. Ongoing auditory habilitation should focus on supporting the family and should partner the parent and other caregivers with professionals, including pediatricians, otologists or otolaryngologists, geneticists, audiologists, early-intervention providers, educators, and speech-language pathologists. Working to support family choice in technology and communication methodology is rewarding and it challenges professionals to remain informed and unbiased.

Sandra Abbott Gabbard, PhD, is the Co-Director of the Marmon Downs Hearing Center and an Assistant Professor at the University of Colorado. Jennifer Schryer, AuD, is a Clinical Instructor at the University of Colorado Health Sciences Center. Readers may contact Dr. Gabbard at Sandra.Gabbard@uch.edu or at Audiology Clinic, UCHSC, P.O. Box 6510, Mail Stop F 736, Aurora, CO 80045.

REFERENCES